

## Introduction

This Addendum provides American Shad passage performance criteria in support of achieving the goal and objectives of the Connecticut River Atlantic Salmon Commission's (CRASC) Connecticut River American Shad Management Plan (Plan). The Plan, approved in 2017, identified the following three broad objectives for fish passage:

- 1.5 *Establish safe, timely, and effective upstream and downstream fish passage for returning adults, post-spawn adults, and juveniles; and*
- 1.6 *Establish upstream passage performance measures, addressing fishway attraction, entry, internal passage efficiency, and delay at these three life stages, as suitable information is available, to support other objectives of this Plan; and*
- 1.7 *Establish downstream performance measures, for adult and juvenile life stages that maximize survival for through-project passage and that address downstream bypass route attraction, entry, passage efficiency, and delay, as suitable information is available to support objectives of this Plan.*

The state and federal fishery management agencies, through their individual and cooperative authorities (CRASC and ASMFC), are committed to restoring American Shad in the Connecticut River basin, and achieving the Management Plan's goal and objectives. Those goals and objectives are dependent on having safe, effective and timely fish passage for both adult and juvenile American Shad at in-river barriers. Defining fish passage criteria for what is safe, timely and effective is necessary in order to evaluate and manage progress towards these goals and objectives. A FERC Environmental Assessment for the American Tissue Project (2018<sup>A</sup>) stated, "*Commerce and Interior have not included any specific performance standards that would be used to test the effectiveness of the fish passage facilities...Without specific performance standards to analyze, there is no basis for assessing the benefits of effectiveness testing for fish passage and determining whether effectiveness testing would or would not provide benefits to alosines....*" (FERC 2018<sup>A</sup>).

Effectiveness is ultimately the result of both safety and timeliness. Ideally, for a facility/project to have zero effect on migrating fish, 100% of fish that arrive at the station would pass with no delay, injury, or mortality. Here, we attempt to provide realistically achievable performance measures that balance regulatory objectives with feasible monitoring methods.

**The following are the Fish Passage Performance Criteria or Objectives for both adult (upstream and downstream) and juvenile (downstream) American Shad for hydroelectric projects in the Connecticut River basin:**

1. Upstream adult passage minimum efficiency rate is **75%**, based on the number of shad that approach within 1 kilometer of a project area<sup>A</sup> and/or passage barrier. Passage efficiency is  $[(\# \text{ passed} / \# \text{ arrived}) * 100]$ ;
2. Upstream adult passage time-to-pass (1 kilometer threshold) is **48 hours or less** based on fish that are passed (requires achieving Objective #1);
3. Downstream adult and juvenile project passage minimum efficiency and survival rates are each

**95%**, based on the number of shad that approach within 1 kilometer of a project area<sup>A</sup> and/or passage barrier and the number that are determined alive post passage (not less than 48 hours evaluation). Passage efficiency is  $[(\# \text{ passed}/\# \text{ arrived}) * 100]$  and passage survival is  $[(\# \text{ alive downstream of project}/\# \text{ passed}) * 100]$ .

4. Downstream adult and juvenile time-to-pass is **24 hours or less**, for those fish entering the project area<sup>A</sup>.

<sup>A</sup> – Project area shall be defined as comprising the river within 1 km of the up- and downstream extent of a hydropower facility and its footprint components. Where a powerhouse is separated from a dam, e.g. by a power canal, this will also include any bypassed reach of the river. The applied definition for 1 km threshold, in cases whereby a bypassed river reach exists (with regulated/alterd flows) from the development and use of a power canal system, by hydropower operators. In such cases, the location of the dam proper may be several kilometers upstream of the terminus of the power canal system. For upstream passage, the terminus of the power canal and any associated hydropower facility will be the approach basis for the 1 km project area, not the dam. Alternately, for downstream passage, the dam and gatehouse will serve as the basis for the 1 km project approach area, not the generation facilities in the power canal.

## Strategies

The efficacy of any fish passage structure, device, facility, operation, or measure depends on a variety of factors including site-specific considerations. The information provided below serves as generic guidance and is not intended to categorically replace site-specific recommendations, limitations, or protocols

The morphology, swimming capability, behavior, and life history of American Shad create challenges for upstream and downstream passage through engineered fishways. The following strategies and best practices provide guidance for the design and operation of efficient fishways for American Shad.

1. Proposed new, and/or modifications to existing, fish passage facilities and any related project operations, should meet or exceed design criteria detailed in the USFWS Fish Passage Engineering Criteria Manual (2017) or its most current version. Proposed variations from USFWS Criteria Manual in either proposed new structures and/or modification to existing structures/operations will require consultation with the federal fish passage engineers (NOAA and/or USFWS). The FERC (2018<sup>B</sup>) in its own analyses has stated, “...*designing the upstream anadromous fish passage facility consistent with FWS’s 2017 Design Criteria Manual and in consultation with the resource agencies as stipulated by Interior’s and NMFS’s fishway prescriptions would help guide the design process and ensure the upstream fishway is likely to be effective in timely passing any adult salmon returning to the base of the project’s dam upstream...*”
2. General Movement
  - A. Entrances. Fishways, by necessity, are (relative to the size of the river) narrow pathways that fish must discover. When reaching a stream barrier, shad, in general, do not explore to the degree salmonids do (Larinier and Travade, 2002). Multiple entrances may be necessary where

flow conditions are diverse, the river is wide, or sources of false attraction are longitudinally separated (e.g., a bypassed reach between spillway and powerhouse discharge).

- B. Space. Shad move in schools and only reluctantly move as individuals (Larinier and Travade, 2002). Fishways should be as wide as possible to allow the migrants to efficiently move in as a group.
- C. Turns. Shad exhibit rheotaxis and align to the flow field. Shad in particular seem hindered by diverse and shifting flow fields. To the extent possible, fishway designs should ensure that anthropogenic structures do not create large-scale eddies, which can confuse shad and delay passage. Within fishways, sharp turns greater than 90 degrees should be avoided; where necessary, 180-degree turns can be accomplished with two 90-degree turns separated by a sufficient distance.

### 3. Hydraulic Structures

- A. Orifices. While shad may move through much of the water column, they are typically reluctant to move through submerged orifices. Managers, designers and operators should not expect shad to move through orifices in the weir walls of pool-type fishways (orifices are generally used to drain and maintain hydraulic conditions). Fishway entrance and exit gates should not be operated in an orifice condition; gate lips should be maintained above the waterline during passage season.
- B. Vertical Slots. Shad are reluctant to move through constrictions as individuals, but will do so slowly (compared to salmonids). To promote movement and ensure the opening is wide enough to limit abrasion injuries on concrete walls, the slots for a vertical slot fishway should be no less than 18 inches wide (USFWS 2019).
- C. Denil Baffles. Standard Denil baffles are typically built in 2-foot, 3-foot, and 4-foot widths depending on site constraints, hydrology, population size, and species. Given the shad's reluctance to move individually, and its hesitancy to navigate tighter flow constrictions, Denil fishways for shad should be 4-feet wide (USFWS 2019).
- D. Upstream Fishway Weirs. Shad do not leap like salmonids; accordingly, the nappe of flow over a weir should be non-aerated and submerged (i.e., the water surface on the downstream side should be level with, or above, the weir crest). Additionally, the jet of flow over the weir should produce streaming conditions rather than plunging conditions (USFWS 2019); this promotes a forward roller (i.e., hydraulic) in the downstream pool. An optimal depth of flow over the weir crest is typically in the range of 12 to 18 inches, depending on other conditions.
- E. Downstream Bypass Weirs. Negative rheotaxis guides downstream migrants (adults and juveniles) to the accelerating flow over a weir. However, rapid spatial accelerations (i.e., large changes in velocities over short distances) can spook shad leading the fish to reject the bypass. For this reason, a broad-crested weir is preferable. Bypasses should not approximate a sharp-crested weir (e.g., simple weir boards), if possible. A uniform acceleration weir (UAW) is ideal; UAWs have been shown to moderate this rejection behavior in shad by slowly accelerating the flow as it moves over the bypass (Haro et al. 1998). Weirs should be at least 3-feet wide and maintain 2 feet of depth at all times.
- F. Turbine Intakes Racks. Racks or screens should have a 1-inch clear spacing or less. This promotes a behavioral avoidance reaction in adult shad that reduces entrainment and impingement. If feasible, racks should be built at a 45° degree angle to the approach (free

stream) velocity and lead to a downstream bypass. This arrangement promotes a sweeping flow (leading to the bypass) that encourages the animal to seek its own escape route. The normal velocity (i.e., velocity measured perpendicular to the plane of the rack) should be maintained at 2 fps or less, measured 1 foot in front of the rack (USFWS 2019).

#### 4. Flow Characteristics

- A. Water Velocity. Shad can sustain burst speeds of 10.2 to 15.4 fps for 6 to 7 seconds. Shad in a 98 foot long flume with velocities ranging from 11.5 fps to 13.6 fps could not reach the end of the flume (Theodore Castro-Santos, personal communication). In general, velocities greater than 6 fps maintained for extended distances can prove challenging (Larinier and Travade, 2002). To limit fatigue, in pools, flumes, and channels, water velocities should be maintained in the 1 to 2 fps range. Localized (short distance) higher velocity regions are necessary to promote movement or attraction: 3 to 5 fps is typical over weir crests; 5 to 6 fps is common through vertical slots; and 4 to 6 fps at fishway entrances has been shown to promote attraction and entry for the suite of anadromous fish on the Connecticut River. For dedicated shad fishways (i.e., where the passage of smaller, weaker fish is neither critical nor desirable), localized entrance velocities of up to 8 fps may be effective.
- B. Turbulence and Air Entrainment. Minimizing turbulence and associated air entrainment is generally considered advantageous in the design of fish passage facilities (Towler et al. 2015). Volumetric energy dissipation correlates to the phenomena of turbulence and aeration in fishways. For shad-specific pool-type fishways, the pool size and flow rate should be designed and operated to limit the dissipation rate to 3.15 ft-lbf/s/ft<sup>3</sup> (USFWS 2019; Towler et al. 2015).
- C. Depth of Flow. To promote movement in shoals, fishway pools, exit flumes and entrance channels should maintain a depth of 4 feet at all times (Turek et al. 2016). Note: this does not apply to smaller shad fishways such as the 4-foot wide Denil. To provide sufficient depth for shad to swim normally, the depth of flow should be greater than or equal to two times the largest adult's body depth at all times (USFWS 2019). At fishway entrances, gates and weir boards are used to vertically constrict depth and accelerate flow; however, excessive constrictions may adversely affect entry rates. Denil entrances should always maintain a minimum of 2 feet of depth above the channel invert, gate lip, or weir boards. At large fishways designed to pass American shad, entrances should maintain 3.0 feet of submergence (Mulligan et al., 2018). Submergence depth is calculated as the vertical distance between the tailwater and crest of the entrance gate.

#### 5. Other Considerations

- A. Light and Shadow. Shad are sensitive to sudden changes in light. Generally, fishways should remain uncovered, or covered by grating that allows natural light on the water surface. Where covered and underground sections of fishway are necessary, lighting should be provided (Larinier and Travade, 2002).
- B. Sounds. American shad have particularly acute hearing. Experience suggests they can be easily stressed by sudden noise (e.g., crowder gate cycling) or influenced by persistent mechanical sound (e.g., powerhouse). To the extent feasible, efforts should be taken to limit artificial sound in, or near, a fishway.

- C. Mechanical and Structural Hazards. Shad often move along walls and in great numbers (Larinier and Travade, 2002). Protuberances, obstacles and moving mechanisms in the fishway can be injurious. Such features should be removed or covered where possible. Vestigial hardware (e.g., bolts, rebar, and antenna connections) on walls should be removed or ground off. Exposed cables in traps should be sheathed in HDPE pipe or hose (or equivalent). Gaps on the sides of gates at counting facilities should be covered with rubber skirts.

### Supporting Narrative

Numerous published and unpublished studies have documented American Shad passage and movements in the Connecticut River basin, particularly on the main stem. The recent peer-reviewed publication “A dam passage performance standard model for American Shad” (Stich et al. 2018) utilized a stochastic life-history based model *“to estimate effects of dam passage and migratory delay on abundance, spatial distribution or spawning adults, and demographic structuring in space and time.”* Stich et al. (2018) provides details of the model design, parameters, inputs and R code scripts. The FERC (2004) has concluded, *“...it is important to recognize the significance of modeling tools for assessing fish passage improvements at multiple projects in a river basin. Considering fish passage effectiveness from this level of analysis provides a meaningful approach because cumulative benefits of fish passage and all other restoration measures in the basin can be assessed.”*

For this Addendum, the Stich et al. American Shad Passage Model was programed to run a suite of passage settings specific to the Connecticut River to help inform criteria development based on four model run outputs and the CRASC Management Plan goal and objectives. For each of the three main stem dams (Holyoke, Turners Falls, and Vernon), upstream passage efficiencies were run at 55%, 65%, and 75%. This rate is based on the number of fish that reach within 1 km of the “project”. Time to pass upstream on individual fish arrival was run at 24, 48 and 72 hours. Downstream passage efficiency and survival at the three projects were run at 75%, 85% and 95% (model uses same value for adult and juvenile). Northfield Mountain Pumped Storage, for only juvenile downstream passage efficiencies and survival, were run at 75%, 85%, and 95%. Outputs of the model, that relate to the Plan include; 1) abundance at river mouth, 2) abundance upstream of Turners Falls Dam, 3) abundance upstream of Vernon Dam, and 4) proportion of repeat spawners ( $\geq$  age-6). The first model run for “abundance at river mouth” suggested that if managers were only concerned with achieving that minimum target, with no concern for “upper” basin distribution, limiting upstream access could yield the minimum target to the river mouth, but notably only with downstream passage and survival  $\geq$  95%. However, the Plan intends to achieve multiple abundance objectives that reduces the priority of a single target. The second model run examined outputs for shad abundance upstream of Turners Falls, exceeding minimum Plan targets for all three upstream passage rates, with the highest outcomes again tied to 95% downstream passage efficiency and survival and highest upstream passage outputs tied to shortest time to pass (24 hours). The third model run examined abundance upstream of Vernon Dam, exceeding Plan minimum targets for all three upstream passage rates, with the highest outcomes also tied to 95% downstream passage efficiency and survival and upstream passage occurring in a tiered manner (highest outputs are for shortest time to pass [24 hours]). The fourth model run examined outputs for repeat spawner component (age-6) at the river mouth, demonstrating a consistent increasing trend in repeats from incrementally improved downstream passage efficiencies and survival (95% highest).

The American Shad Passage Model is one tool for managers to assess the function of fish passage and protection measures required at hydroelectric facilities on the Connecticut River. Results of the

Connecticut River model runs are consistent with the findings in Stich et al. (2018), for the multi-dammed Penobscot River. The published article by Stich et al. (2018) and the model run specific to the Connecticut River highlight the importance of high downstream passage efficiency/survival (95%) for adults and juveniles in order to realize actual population gains by providing access upstream at successive dams and maintain a substantial repeat spawner component. Downstream passage was consistently important in all four Connecticut River model run outputs. For upstream passage efficiency rates, abundance outputs were also consistently maximized with shorter time to pass (24 hours), for abundance levels upstream of Turners Falls and Vernon dams.

Downstream passage of adult as well as juvenile shad are a concern in the Connecticut River basin from the perspective of cumulative effects, whereby seemingly modest levels of loss at one hydropower project (e.g., 10-15%) can be compounded at subsequent projects to greater levels affecting both ecological contributions of juveniles and adults, future abundance and population structure/dynamics. Repeat spawner females have an exponential increase in fecundity resulting in substantially greater reproductive potential than smaller virgin females. Given this, a return to >30% repeat spawners for this population has the potential to substantially increase the reproductive potential of the current high proportion of “virgin” female component currently observed in the Connecticut River, while at the same time creating population resilience or buffer against poor recruitment years. Having an age structured population comprised of a substantial proportion of fish age-6 to age-9 will help achieve the Plan’s goals and objectives, but is requisite on managing anthropogenic sources of mortality, such as turbine passage impacts. In addition, recent assessment work has demonstrated density-dependent effects on juvenile shad growth and condition in the Holyoke to Turners Falls reach in contrast to the Vernon to Bellows Falls reach (Mattocks et al. 2019). Management actions that result in a better distribution of juvenile densities will improve juvenile growth and condition. These data further support the complementary need of having high passage efficiency and survival rates for adults (up and down), and juveniles to mitigate for repeated turbine/facility exposures to access and utilize historic upstream habitats.

The question of whether a new hydroelectric project can impact (type and extent) an existing American Shad population has been studied on the Annapolis River, Nova Scotia, Canada. A tidal dam across the Annapolis River was created in 1983 with a spillway/tide gate. A power station with a 7.6 meter (m) diameter turbine, operating at 50 RPMs, under a head range of 1.4 – 6.8 m has operated since 1984 with only upstream passage in place. Dadswell et al. (2018) utilized pre-hydropower fish assessment data for American Shad and other species, to document population impacts largely attributed to this hydropower facility. The researchers provide data demonstrating declines in American Shad adult lengths, mass, age, and percent repeat spawner with a corresponding increase in total annual adult mortality. The authors state that *“these significant changes were largely due to turbine mortality of adult A. Sapidissima during post-spawning outmigration. The tidal turbine is apparently removing larger older adults from the population because they have a higher probability of strike and have passed through the turbine repeatedly during successive, annual spawning runs.”* On the Connecticut River this situation is analogous with repeated successive dam/power stations. The researchers note acoustically tagged adult shad passed via the Annapolis Station turbine had a reported mortality rate of 46.3 (±34.7)% in 1985 and 21.3 (±15.2)% in 1986. Based on adult shad size (400-600mm) the authors note a probable blade strike of between 12.5 and 18.7% [rates similar to many estimates for Connecticut River basin turbines].

Adult shad that successfully pass Vernon Dam have access to the most upstream historic extent of their habitat but must later negotiate three main stem barriers on their post-spawn outmigration. For these fish an 85% downstream passage efficiency/survival rate at each project, results in only 61% of the

starting number. However, with the exclusion of adult shad from turbine passage and/or other routes of additive project mortality, to achieve a through project target efficiency/survival rate of 95% at each project, the resultant outcome is 86% of the starting number. Thus, a 10% improvement in passage efficiency/survival translates to a 25% increase in bypassed fish to the lower river from this habitat.

Hydroelectric plants dramatically influence the flow fields in a river upstream and downstream of the project. Turbine discharge typically serves as the significant and persistent source of far-field attraction to migrating fish above and below dams. In the context of downstream passage of American shad, turbine passage is hazardous to both juveniles and post-spawn adults; entrainment should generally be avoided. Adult shad are relatively large fish, with females being larger than males (at age and in the annual run composition) and therefore more susceptible to blade strike (Figure 1). The conventional mitigation strategy is to install a dedicated downstream fishway that allows out-migrating juveniles and post-spawn adults to safely bypass the turbines. The efficacy of the bypass depends, in turn, on the same flow fields created by the turbines and any fish guidance structure including how fish are conveyed to a receiving waters and the associated concerns with that process and the receiving pool (USFWS 2019).

Where the efficacy of a downstream bypass is low (or the bypass is non-existent), careful analysis of the mortality of fish entrained through turbines should be made. Field studies (e.g., mark-recapture, balloon-tags) that empirically measure survival of entrained fish are preferred. Moreover, site-specific studies are recommended; extrapolating total entrainment rates from samples of other species or from other sites may be less precise (FERC 1995). Where field studies are impractical, infeasible, or cost prohibitive, desktop analyses may prove useful predictive tools.

Numerous desktop techniques have been documented and generally fall into one of two categories: empirically derived regression equations and fundamental methods that relate fish physiology and turbine physics. The so-called Von Raben method and Franke method are examples of the latter type. Both methods yield equations that predict the probability of blade strike depending largely on turbine geometry and fish length (Franke et al. 1997). The Franke method, an extrapolation and improvement upon Von Raben approach, is the preferred fundamental desktop analyses method. The CRASC recommends the following best practices:

- the Franke method should only be used for Francis, Kaplan, and fixed propeller turbines;
- where possible, use engineering drawings (rather than reports) to determine the inlet and outlet diameters on a Francis turbine;
- in the absence of better information, assume mid-blade paths for fish moving through Kaplan and fixed propeller turbines;
- where accurate turbine efficiency curves for a site are not available, typical turbine efficiency curves can be used and, perhaps, discounted depending on the condition of the runner;
- care should be taken in selecting a value of the mortality correction factor or correlation coefficient, Lambda; unless Lambda has been calibrated, a conservative value of 0.2 is recommended.

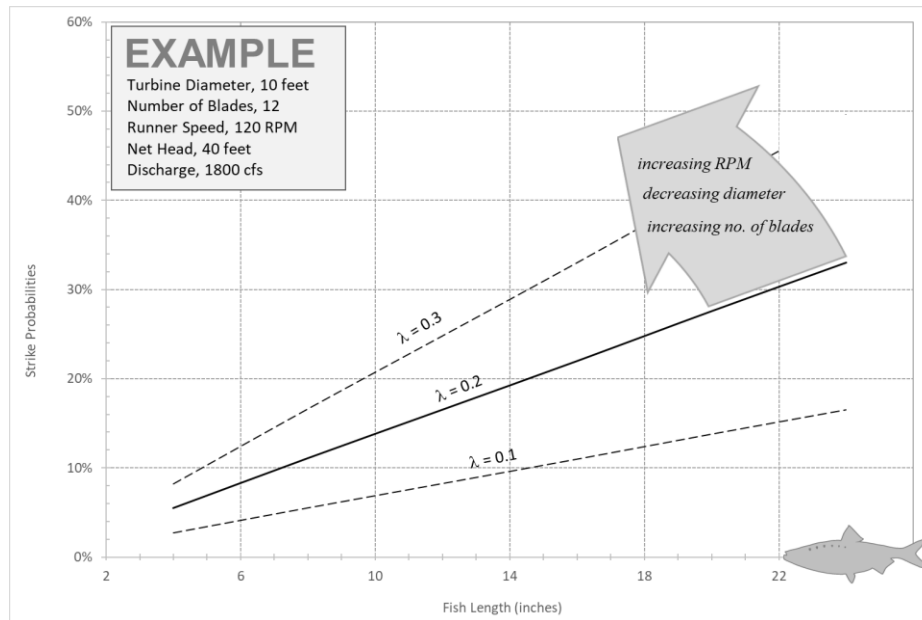


Figure 1. Blade strike probabilities for an example turbine in relation to selected Lambda and responses to increases in turbine RPM, fish length, decreases in turbine diameter, and increases in number of turbine blades.

While the appeal of desktop methods is clear, their application can be computationally complex and is best suited for a spreadsheet solution. To facilitate this, in 2018 the USFWS developed a computer implementation of the Franke method for Microsoft Excel™. This model is a probabilistic Excel-based, VBA application of the methods outlined in INEL's "Development of Environmentally Advanced Hydropower Turbine System Design Concepts" by G. Franke et al. (1997) for evaluating fish mortalities due to turbine entrainment. This model, provided "as is" and without warranty of any kind, is available for download from:

[www.fws.gov/northeast/fisheries/fishpassageengineering.html](http://www.fws.gov/northeast/fisheries/fishpassageengineering.html)

Juvenile shad mortality based on blade strike model probabilities have shown consistency for short-term (24 hr) mortality with field studies at several hydroelectric projects using balloon tagged juveniles passed through turbines, in a peer-reviewed study design (Heisey et al. 1992). However, juvenile fish field studies have been unable to quantify long-term delayed mortality that may occur from injuries (injury rates are often quantified in study recovered juveniles). The difficulty in retaining control fish for >48 hours is the cause of the issue, resulting in only immediate mortality estimates in recent study results.

Adult shad mortality, based on turbine blade strike model probabilities are increased greatly based on the size of the fish, as noted earlier (Figure 1). Unlike juvenile shad, the ability to use balloon tag methods and pass post spawn shad through turbines has not been successful, attributed to the reduced condition of fish having spent 4-6 weeks in-river without feeding and elevated water temperatures. In recent years, radio tags that can be programed to switch burst signal frequency, based on an internal ball bearing movement or lack of movement, has been used to assess mortality. However, several important limiting considerations with this tag type for analyses of "turbine" passed adult shad must be recognized. First, these tags must be programed for a period of "inactivity" before the tag signal



switches from (as an example) an interval of 3 seconds to an interval of 10 seconds. This trigger period has often been set to 24 hours that leads to a complete lack of credibility for a “live signal” following turbine passage, for at least the first 24 hours in the case of immediate mortality. Second, dead fish drift has been studied and documented, including on the Connecticut River with dead radio-tagged adult American Shad, directly inserted into the Holyoke Dam Hadley Falls Station turbine intakes. Bell and Kynard (1985) demonstrated dead turbine-passed adult shad, passed through Hadley Falls Station, drifted between 0.6 and 1.3 km downstream of the project in less than 24 hours of mobile radio tracking. Havin et al. (2017) also provides study results on the drift of dead salmon smolts (2.4 km) and eels (up to 30.1 km). Third, recognizing that dead fish drift, there is the potential that dead tagged individuals will not trigger the mortality switch and/or may alternate between a live signal and mortality signals in areas where drift/movement occurs (e.g., the tailrace of generating turbines).

Castro-Santos et al (2016) determined upstream passage efficiency rates for adult shad using radiotagged fish in 2011 and 2012 from the river mouth to the Holyoke Dam and its two fish lift fishway system (Castro-Santos et al. 2016). These researchers capture and dual tagged American Shad with a radio tag and a PIT tag alone, allowing adjustments for radio tag shedding. Study methods also included deploying a number of stationary radio receivers along the main stem river and also in and around the Holyoke Dam. A PIT reader and antennas were deployed at the Holyoke Fish Lift to document a passed shad. Study results using a Cormack Jolly Seber analyses determined arrival rates ( $\pm$  standard error) of tagged shad to Holyoke Dam as  $80.5 \pm 6.5\%$  (2011) and  $77.1 \pm 7.6\%$  (2012). Passage rates of tagged fish that arrived were  $73.8 \pm 7.0\%$  (2011) and  $75.8 \pm 6.6\%$  (2012).

The Vernon Dam fish ladder’s passage efficiency also provides a basis for upstream passage efficiency criteria based on the number of shad counted passing at the Turners Falls gatehouse ladder. Since 2012, when USFWS fish passage engineers identified and fixed within ladder passage issues, annual shad passage counts have provided useful, consistent data on passage with a functioning fishway (Table 1). A 2011 radio telemetry study using American Shad tagged and released into the Turners Falls Power Canal, from the exit of the Cabot Station Fish Ladder, provided a least biased estimate (reduced handling/tagging effects with only viable fish passing through Gatehouse) to more accurately determine the proportion of the shad passing Gatehouse that reach the Vernon Dam tailrace (Castro-Santos 2011). Study results demonstrated 90% of the radio tagged shad (36/40) passing the Gatehouse were detected at a stationary receiver located 1 km downstream of Vernon Dam. Tagged fish moved rapidly to the Vernon Dam project area (median of < 2 days). Subsequent year radio tagging studies (FirstLight Power and TransCanada) had results affected by handling/tagging/tag effects (releases within the Turners Falls impoundment) and/or very limited sample sizes of tagged fish passing upstream of the Turners Falls power canal. Applying the 90% arrival rate for viable radio tagged shad to the observed passage counts differentials for the two facilities, results in Vernon’s upstream passage efficiency averaging 67.7% (Table 1). The removal of the first year (2012) following initial fixes at the facility (time series low) increases the mean passage efficiency rate to 72%.

Table 1. Annual American Shad passage counts for Turners Falls Gatehouse Fish Ladder and the Vernon Dam Fish Ladder for the period 2012 – 2018.

Year	American Shad Passage			At 90% arrival to Vernon, required % passage efficiency for observed counts at Vernon
	TF Gatehouse	Vernon	% Passed from Gatehouse	
2012	26,727	10,386	38.9	43.2
2013	35,293	18,220	51.6	57.4
2014	39,914	27,706	69.4	77.1
2015	58,079	39,771	68.5	76.1
2016	54,069	35,513	65.7	73.0
2017	48,427	28,682	59.2	65.8
2018	43,146	31,724	73.5	81.7
Mean			<b>61.0</b>	<b>67.7</b>
S.D.			<b>12.1</b>	<b>13.5</b>

The CRASC Shad Management Subcommittee anticipates that FERC will issue license articles for Turners Falls, Northfield Mountain Pumped Storage, and Vernon in 2020 and that there will be license articles that address safe, timely and effective passage. Consequently, the improvements to fish passage at each of these facilities will need to be evaluated against the above stated fish passage performance criteria. Licensees of these projects must develop evaluation study plans in coordination with state and federal resource agencies. The results of these studies will allow licensees and resource agencies to consider structural, technical or operational changes if passage performance falls short of the criteria. Considerations for proper study design includes appropriate analytical approaches and adequate sample sizes of test fish to address statistical variability and capture representative variation in project operational and environmental conditions as well as fish movement timing (early, middle, late run) and characteristics of the species life stage (size, physiology). Several peer reviewed studies as well as unpublished evaluations in the Connecticut River have documented the capture, handling, tagging and tag related effects for study fishes using radio or acoustic tags (Frank et al. 2009; Olney et al. 2006; Bailey et. al 2004). Such effects must be taken into consideration when designing, conducting, analyzing and interpreting study results. Tag manufacturers and researchers have made advances in smaller radio tag sizes, tagging methods, analyses, and approaches to describe the type and extent of effects (e.g., PIT only tagged fish vs. radio & PIT tagged fish). Radio and acoustic tags in addition to PIT tags remain a primary evaluation method to understanding underlying behavior and movement, but other approaches may also be applied such as video/acoustic monitoring with caveats based on field of coverage and resolution. The state and federal agencies will provide further guidance during the consultation process.

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